Visual motion interferes with lexical decision on motion words

Lotte Meteyard[1,3,*], Nahid Zokaei[1], Bahador Bahrami[1,2] and Gabriella Vigliocco[1]

Embodied theories of cognition propose that neural substrates used in experiencing the referent of a word, for example perceiving upward motion, should be engaged in weaker form when that word, for example ‘rise’, is comprehended [1–3]. This claim has been broadly supported in the motor domain (for example [4,5]), whilst evidence is supportive, but less clear cut, for perception (for example [6–8]). Motivated by the finding that the perception of irrelevant background motion at near-threshold, but not supra-threshold, levels interferes with task execution [9], we assessed whether interference from near-threshold background motion was modulated by its congruence with the meaning of words (semantic content) when participants completed a lexical decision task (deciding if a string of letters is a real word or not). Reaction times for motion words, such as ‘rise’ or ‘fall’, were slower when the direction of visual motion and the ‘motion’ of the word were incongruent — but only when the visual motion was at near-threshold levels (supporting [9]). When motion was supra-threshold, the distribution of error rates, not reaction times, implicated low-level motion processing in the semantic processing of motion words. As the perception of near-threshold signals is not likely to be influenced by strategies [9], our results support a close contact between semantic information and perceptual systems.

During lexical decision, words were presented on a screen until a response or for 1500 ms, superimposed at onset on a 200 ms dynamic visual motion pattern [6] (Figure 1) containing either upwards or downwards motion: 30 Up words, such as ‘rise’ or ‘climb’, 30 Down words, such as ‘drop’ or ‘fall’, and 30 Control words, such as ‘kick’ or ‘eat’, were selected from a list previously normed for spatial characteristics [6]. This produced three conditions: Match, where visual display and word-meaning were congruent; Mismatch, where visual display and word-meaning were incongruent; and Control, where the words did not refer to vertical motion. In Experiment 1, near-threshold motion coherence was achieved by setting the dynamic visual motion at the individual observer’s predetermined detection thresholds for upwards and downwards motion (see Supplemental data available on-line with this issue). In Experiments 2, 3 and 4, motion was supra-threshold: dynamic visual motion coherence was set to 30, 60 and 90%, respectively, to ensure that the same result was seen for different levels of salient motion, in line with [9].

There were no significant effects of the experiment on the reaction time or error data, so Experiments 2, 3 and 4 were collapsed into one supra-threshold data set and compared to Experiment 1 (near-threshold). For reaction times, the main effect of the experimental Condition (Match or Mismatch) was significant ($F(2,206) = 4.884$, $p < 0.01$), as was the interaction between Condition and Experiment ($F(2,206) = 3.158$, $p < 0.05$). Planned comparisons showed significantly longer reaction times for the Mismatch condition as compared to both Control (mean difference, Md = 0.343, SE = 0.114, $p < 0.01$) and Match (Md = 0.316, SE = 0.133, $p < 0.05$) conditions when motion was near-threshold (Experiment 1) but not supra-threshold (Experiments 2, 3 and 4). Errors showed a significant main effect of Condition ($F(2,148) = 6.339$, $p < 0.005$) when motion was supra-threshold (Experiments 2, 3 and 4), with less errors in the Control condition as compared to the Match (Md = –0.829, SE = 0.315, $p < 0.05$) and Mismatch (Md = –1.03, SE = 0.315, $p < 0.005$) conditions. There were no differences between condition error rates when motion was near-threshold (Experiment 1; see Figure 2 and Supplemental data).

In line with [9], we suggest that automatic activation of the motion-responsive visual area MT+ by threshold level stimuli — which is not under executive control — gives rise to the interference between perceptual and semantic information processing seen in reaction times for Experiment 1. The lack of interference when motion was supra-threshold is in line with the finding that

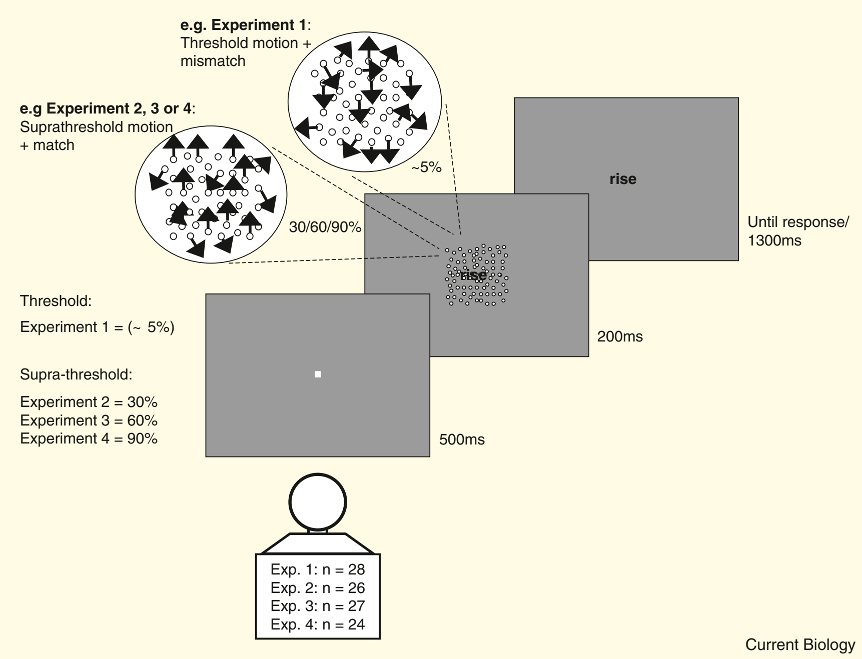

Figure 1. Experimental design.

Participants were presented with words for lexical decision, and Motion Coherence was manipulated between-subjects. In Experiment 1 a dynamic visual motion pattern with ~5% of dots moving coherently (at each individual’s threshold level) was presented at word onset, in Experiments 2, 3 and 4 the dynamic visual motion coherence was constant at 30, 60 or 90% of dots.

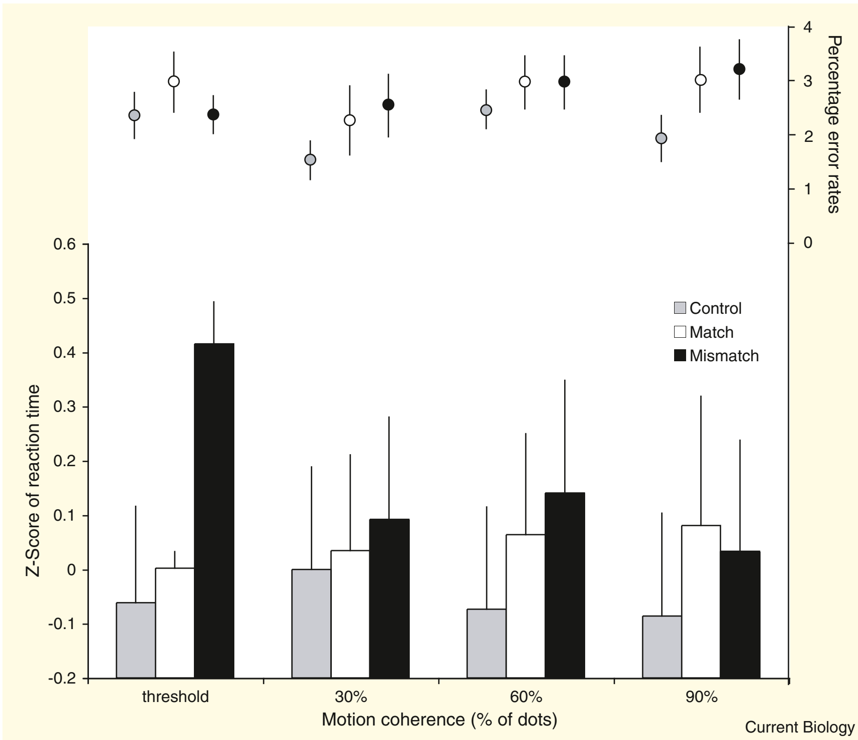

Figure 2. Mean Z-score of reaction time and percentage error rates by condition and experiment.

In order to compare across experiments, reaction times were normalised as Z-scores relative to the control condition for each experiment. Reaction times are longer only when the visual motion pattern is near-threshold <u>and</u> incongruent with semantic information. This supports the finding that near-threshold motion is not suppressed, so it is able to interfere with other processes [9]. This interference is semantically modulated (being present only in the Mismatch condition) linking non-strategic processing of visual motion with the semantic representation of motion words. Errors are presented as a percentage of the total completed experimental trials. More errors are produced when motion is salient and the lexical decision is performed on motion words, regardless of congruence. This pattern holds across all three suprathreshold Experiments, suggesting that semantic content referring to motion is disrupted when salient motion signals are suppressed by executive processes [9]. Error bars are one standard error.

supra-threshold motion can be suppressed by higher level, top-down cognitive mechanisms involving inhibitory feedback from dorso-lateral pre-frontal cortex to motion sensitive area MT+ in the human brain [9]. Irrelevant motion at or near threshold levels does not seem to initiate such suppressive feedback [9]. The distribution of error rates support the inference that suppression of supra-threshold motion signals disrupts semantic processing for all motion words (regardless of congruence).

These results demonstrate that low-level visual motion representations are engaged in the semantic processing for words referring to motion, in line with claims from embodiment [1–3] and arguing against classically symbolic theories of semantic representation (for example [10]). Reaction times were longer for the Mismatch condition when motion was near-threshold, supporting the view that the words' semantic content is integrated involuntarily and automatically with the near-threshold visual motion signal, which then gives rise to interference when the semantic and the perceptual information mismatch (Experiment 1). The incongruent visual motion signal appears to be confused with semantic motion information, creating noise that slows the lexical decision. Conversely, more errors were produced for all motion words, as opposed to control words, when motion was supra-threshold. The suppression of salient motion signals may hamper the verification of semantic motion information, producing more errors during lexical decision. Neither facilitation nor interference was seen in isolation when visual and semantic motion were congruent, suggesting intimate connections (rather than an isomorphism) between visual and semantic motion representations.

Previous experiments have found that a prolonged salient motion stimulus interferes with the judgement of concurrently presented congruent motion sentences [8]; if adaptation to that stimulus inhibited directionally selective motion processes, the data converge by demonstrating that the inhibition of motion processing affects the processing of semantic motion. Congruent interference may not have been found in our data because inhibition was short lived (as was the motion stimulus) and single words, rather than sentences, were used. In sum, these data begin to clarify how semantic, perceptual and executive systems interact.

Supplemental data

Supplemental data are available at http://www.current-biology.com/cgi/content/full/18/17/R732/DC1

References

1. Barsalou, L.W. (1999). Perceptual symbol systems. Brain Behav. Sci. *22*, 577–660.
2. Gallese, V., and Lakoff, G. (2005). The brain's concepts: The role of the sensory-motor system in conceptual knowledge. Cogn. Neuropsychol. *22*, 455.
3. Pulvermüller, F. (1999). Words in the brain's language. Brain Behav. Sci. *22*, 253–336.
4. Boulenger, V., Roy, A.C., Paulignan, Y., Deprez, V., Jeannerod, M., and Nazir, T.A. (2006). Cross-talk between language processes and overt motor behaviour in the first 200msec of processing. J. Cogn. Neurosci. *18*, 1607–1615.
5. Glenberg, A.M., Sato, M., and Cattaneo, L. (2008). Use-induced motor plasticity affects the processing of abstract and concrete language. Curr. Biol. *18*, R290–R291.
6. Meteyard, L., Bahrami, B., and Vigliocco, G. (2007). Motion detection and motion verbs: Language affects low-level visual perception. Psychol. Sci. *18*, 1007–1013.
7. Spivey, M.J., and Geng, J.J. (2001). Oculomotor mechanisms activated by imagery and memory: eye movements to absent objects. Psychol. Res. *65*, 235–241.
8. Kaschak, M.P., Madden, C.J., Therriault, D.J., Yaxley, R.H., Aveyard, M., Blanchard, A.A., *et al.* (2005). Perception of motion affects language processing. Cognition *94*, B79.
9. Tsushima, Y., Sasaki, Y., and Watanabe, T. (2006). Greater disruption due to failure of inhibitory control on an ambiguous distracter. Science *314*, 1786–1788.
10. Levelt, W.J.M., Roelofs, A., and Meyer, A.S. (1999). A theory of lexical access in speech production. Behav. Brain Sci. *22*, 1–75.

[1]Department of Psychology, University College London, 26 Bedford Way, London WC1H 0AP, UK. [2]Institute of Cognitive Neuroscience, University College London, 17 Queen Square, London WC1N 3AR, UK. [3]MRC Cognition and Brain Science Unit, 15 Chaucer Road, Cambridge CB2 7EF, UK.
*E-mail: meteyard@gmail.com